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13. ABSTRACT (Maximum 200 words)

An international workshop on benchmarks in contact mechanics and friction damping was held on the 12TH and 13TH of May in conjunction with the DoD sponsored HCF Conference in West Palm Beach, FL. The workshop was organized by Dr. J. H. Griffin, a Professor at Carnegie Mellon University in Pittsburgh, and Dr. E. Ewins, a Professor at Imperial College in London. The workshop was a follow-on to a workshop held last year. Its primary purpose was to define an appropriate set of benchmarks to provide a basis for direct comparison of existing methods and procedures as well as to provide reference test cases for future methods development. A secondary objective of the Workshop was to consider ways to move forward once these benchmarks have been defined.

An announcement was distributed to potential participants, refer to Appendix 1: Announcement. The workshop was attended by both European and American experts from industry, universities and government agencies - see Appendix 2: List of participants.

The first attempt to hold the follow-on meeting was delayed by the events of September 11, 2001 (the meeting was to have taken place in Pittsburgh on 9/13) and as a result of the ensuing delay in rescheduling, some momentum was lost. Another feature that emerged in the period during which the benchmarking meeting was being rearranged was the idea of combining

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Workshop on Benchmark Experiments in Contact Mechanics as Applied to Gas Turbine Engines

WEST PALM BEACH, 12-13 MAY, 2002

Submitted to

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Date: 2 September 2002

1. Introduction

An international workshop on benchmarks in contact mechanics and friction damping was held on the 12th and 13th of May in conjunction with the DoD sponsored HCF Conference in West Palm Beach, FL. The workshop was organized by Dr. J. H. Griffin, a Professor at Carnegie Mellon University in Pittsburgh, and Dr. E. Ewins, a Professor at Imperial College in London. The workshop was a follow-on to a workshop held last year. Its primary purpose was to define an appropriate set of benchmarks to provide a basis for direct comparison of existing methods and procedures as well as to provide reference test cases for future methods development. A secondary objective of the Workshop was to consider ways to move forward once these benchmarks have been defined.

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The first attempt to hold the follow-on meeting was delayed by the events of September 11, 2001 (the meeting was to have taken place in Pittsburgh on 9/13) and as a result of the ensuing delay in rescheduling, some momentum was lost. Another feature that emerged in the period during which the benchmarking meeting was being rearranged was the idea of combining the original 2001 Contact Mechanics Workshop group with another similar group who had participated in a Joints Dynamics Workshop at Sandia National Labs in April 2000. There was some overlap in the subject matter and membership of the two groups and it was felt that it might be useful to draw on both communities in the follow-on workshop.

2. Workshop Agenda

The planned schedule for the 2nd Workshop ran from 1300 on 12th May to 1230 on the 13th, with the following outline agenda:

1. Welcome & Introductory Comments
2. Review and Summary of Previous Workshop (6/01)
3. Requirements , Concepts and Specifications for Benchmarks in Contact Mechanics
4. Ideas for Benchmarks
5. Future Activities and Plan of Action

This schedule was essentially followed at the workshop. Item 2 extended longer than originally planned, not least because there were several attendees who had not been present at the first Workshop and who understandably raised several issues that had been debated at length on the previous occasion. It was also clear that several of the 'new' participants were not drawn from the aero engine community and so had a very different

perspective on the topic of discussion, and had different interests and potential applications.

It is not intended to report in any detail on the discussions of these issues. Rather, we shall seek to focus on the specific outcomes regarding decisions and suggestions for the benchmarking activities that should be pursued in the future. There were fewer set-piece presentations on this occasion and much of the time was spent in debate, and small group discussion, of the benchmarks themselves.

Some of the new attendees and others presented some existing test benches and procedures as additional input to the portfolio of ideas that could be considered for the benchmarks to be defined in our case. These included:

- Mr Filippi (CMU) on a new rig to measure interface dynamic properties
- Prof Gaul (Stuttgart University) on Fuzzy arithmetic for contact stiffness analysis
- Dr Petrov (Imperial College) on advanced modelling of contact dynamics and the need for validation;
- Prof Ferris (Purdue) on load history effects
- Prof Griffin (CMU) on test on different shaped components

A presentation was also made by Professor Ewins (Imperial College) regarding benchmarks in general and reporting on several that have been undertaken in recent years in the structural dynamics area.

3. Types of Benchmarks

The general discussion on benchmarks for contact mechanics revealed that there were at least three different types that could be of interest:

- Micro level
- Interface level
- System level

In subsequent discussion, it was agreed that only the second and the third of these types were appropriate for the current activities. At each level, both numerical benchmarks and experimental benchmarks are of interest.

The interface level benchmark addresses only a single contact interface and has the function of providing direct experimental measurement of, or of providing confirmation of predictions of, specific interface properties such as coefficient of friction, hysteresis, wear and life characteristics etc. as referred to an incremental area of a specific type of contact. Measurements and/or calculations would be required of contact area, pressure/stress distributions, temperature and normal loads.

The system level benchmark refers to a system or structural configuration that represents a typical application involving two or more structural components and probably several

specific contact regions. It is intended to provide a basis for demonstrating the capability to predict the dynamic behaviour of a structure with active contact surfaces. Measurements and/or predictions would be required of forced response to given excitations, resonance frequencies, mode shapes, effective damping levels and any history dependence that might apply.

A summary of the outcome of discussing these benchmarks is provided in the Appendices C and D, which list the main features required of any benchmarks.

4. Way Forward and Future Actions

In order to make significant progress it was concluded that it is necessary to develop a research program that will provide funding for an international collaborative effort in this area. It was agreed that we should seek the endorsement of the GUIde Consortium on forced response. The GUIde Consortium is a Consortium of US Government agencies (the Air Force, Navy, and NASA) and gas turbine companies (GE, PWA, RR, Honeywell, Siemens Westinghouse, and Mitsubishi America) that coordinates, endorses, and sponsors research related to blade vibration. Professor Griffin is the Director of the GUIde Center at Carnegie Mellon University. It was agreed that Professor Griffin seek GUIde endorsement at the GUIde Annual Review and Business Meeting to be held August 1.

If the area of research is endorsed by GUIde, Professor Griffin will then contact various funding agencies to see if they would be interested in sponsoring research in this area. If a potential funding source can be identified then a program will be developed using the standard GUIde Consortium approach.

1. A RFP (Request For Proposals) will be developed in collaboration with the GUIde Steering Committee.
2. The RFP will be distributed to research institutions that qualify for support by the potential funding agency. (Professor Griffin will try to establish a line of funding that will be open to international applications). The RFP will provide a format and deadline for proposals.
3. The proposals that are received will be evaluated and ranked by the GUIde Steering Committee.
4. Successful proposals will be combined into group proposals and submitted to the appropriate potential funding agency.
5. If the research is funded it will be treated as a GUIde research program. The research will be monitored by a industrial/government team of specialists and progress on the research will be reviewed on an annual basis at the Annual Research Review Meeting.

5. Follow-on Activities

Since the second workshop was held two relevant activities have taken place. Professor Griffin gave a presentation to the GUIde Steering Committee at the GUIde Business

Meeting on 1 August 2002. The GUIde Steering Committee voted to endorse the concept of a new research initiative on contact mechanics and friction damping. Professor Griffin will begin to contact various funding agencies to see if he can identify a potential sponsor.

Secondly, a website has been developed to document the contact mechanics and friction initiative. Its address is: http://www.me.cmu.edu/faculty1/griffin/contactmechanics.htm.

APPENDIX 1: WORKSHOP ANNOUNCEMENT

Workshop on Benchmarks in Contact Mechanics and Friction Damping

WEST PALM BEACH, 12-13 MAY, 2002

Background:

This will be the 2nd workshop on contact mechanics. The purpose of these workshops is to promote the international collaboration of researchers in the fields of contact mechanics and friction damping.

The first workshop focused on assessing the current status of contact mechanics and friction damping technology as it is currently applied to gas turbine engines. A copy of the report summarizing the results of that workshop is attached in a pdf format.

Since we will have a number of new participants in the second workshop, it would be helpful if you took time to read the report from the first workshop. However, I need to make it clear to all participants that we do not have enough time to revisit the first workshop issues.

The purpose of the 2nd workshop will be 1). To define relevant benchmark experiments and computations. 2). To discuss approaches for establishing collaborative research programs.

If you would like to give a short presentation at the workshop (no more than 15 minutes) please send me an abstract and we will try to work it into the schedule.

The preliminary agenda is:

AGENDA: Sunday 12th May 13:00 – 21: 00

1300 – 13:30	Welcome and introductory comments
13:30 – 14:30	Review and Summary of Previous Workshop (6/01) • Contact mechanics modeling for dynamics • Contact mechanics modeling for fatigue stress analysis
15:00 – 17:30	Requirements, Concepts and Specification for Benchmarks in Contact Mechanics • Experimental • Numerical
17:30 – 19:00	Break
19:00	Dinner

AGENDA: Monday 13th May 7:30 – 12:30

07:30 – 08:00	Continental Breakfast
08:00 – 10:00	Ideas for Benchmarks
10:00 – 10:30	Break
10:30 – 12:30	Future Activities and Plan of Action

LOCATION: For details see the attached pdf file.

The workshop will be held Embassy Suites Hotel, Palm Beach Gardens, 4380 PGA Boulevard, Palm Beach Gardens, FL 33410. Phone: 561 622 1000 Contact: Patricia Orem, Events Coordinator. Snack and Sunday dinner are provided by the Workshop. Hotel rooms are available: see the attached pdf file for additional information.

WORKSHOP FEE: After reviewing the costs we have determined that it is not necessary to require a workshop fee. The costs are paid for by our sponsoring organizations: The Air Force Office of Scientific Research and The Sandia National Laboratories.

APPENDIX 2: LIST OF ATTENDEES

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APPENDIX 3: INTERFACE BENCHMARKS

1. Numerical benchmarks will be consistent with experimental benchmarks, i.e. the numerical simulations will try to reproduce the experimental measurements.

2. There are six factors that need to be specified: Geometry, size, surface specifications, load history, materials, friction regime.

   a. Geometry: cylindrical and flat bottom (with radii at corners) specimens on a flat plate. The width of the plate is the same as the width of the specimens so that we avoid singularities at the edges. The radii at the corners get progressively smaller, e.g. the radii = w/2 (the width of the specimen) for the cylinder, radii = w/4, and radii = w/8. The dimensions should be chosen to reflect the size scale of dovetail attachments.

   b. Surface: The specimens should be manufactured all at one time by the same manufacturer and the surface finish should be controlled. Initially, no special surface treatment such as hardening. The test data should be taken in the microslip region so as to minimize gross wear. The data should be taken long enough so that the hysteresis curves are stable.

   c. Materials: titanium and a steel that has a yield strength similar to the materials used for friction dampers.

   d. Loading: initial tests should have constant normal load that is applied first followed by a sinusoidal shear load to cause microslip. Data should be taken for a range of normal loads and shear loads. Later the tests should be expanded to include variable normal load and three dimensional motion. Later the types of shear loads should be expanded to include more complicated load patterns, i.e. other than sinusoidal.

   e. Measurements: The measurements should include hysteresis curves and related variables. The points at which the displacements are to be measured will include points that are more remote (so that they reflect the overall dynamic behavior of the joint and can be used for dynamic characterization of the complete joint) to provide a robust characterization of the interface and measurement of points close to the interface (so that they reflect the contact mechanics more accurately).

APPENDIX 4: SYSTEM BENCHMARKS

Required/Desired Features of Benchmark Configuration

- To have more than one interface, or at least large-area-multiple-contact-points if only one interface is used
- To include load-bearing and/or damping interfaces
- To represent realistic aero-engine applications

Parameters to be Measured and/or Predicted:

Primary Parameters:

- Natural frequencies
- Mode shapes
- Effective damping levels
- Steady-state and transient response characteristics

Secondary, or Detailed Parameters:

- Energy dissipation
- Contact stress distributions
- Subsurface stresses
- Existence of higher harmonics in steady response
- Temperature effects; wear effects
- Normal load variations
- In-plane load variations
- Variation of these properties with time and/or wear

Configurations Proposed:

- Single bolted lap joint in tension
- Two parallel beams joined (bolted) at points along length
- Two-blade + one interblade damping element *(simulates the underplatform damper assembly)*
- Two identical coaxial beams with 3 pin joints (one at each end; one in center)
- Vertical shaft rotating in hole in block
- Two beams connected end to end by clamped dovetail-type joint, loaded in tension and in bending
- Three-blade (2 dummies) + two interblade damper elements *(simulates the underplatform damper assembly)*
- The following was suggested after the workshop: single beam + tip shroud element interfaced to fixed boundaries *(simulates interconnected shrouded blades)*